An Acoustic Resonator for Accurate Measurements of the Prandtl Number of Gases

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We have developed a novel acoustic resonator to accurately measure the Prandtl number of gases. The Prandtl number $(Pr = D_{\nu}/D_{\nu} = \eta C_{\nu}/\lambda)$ is the key parameter for correlating heat transfer between a solid and a moving fluid and it is defined as the ratio of the viscous diffusivity $(D_v = \eta/\rho)$ to the thermal diffusivity $(D_t = \lambda/\rho C_p)$. Our gas-filled cylindrical resonator has a short array of channels placed midway between the ends of the cylinder and oriented parallel to the axis of the cylinder. The channels' occluded volume and the increased surface area perturb the longitudinal acoustic modes of the test gas within the resonator in a predictable way. Odd longitudinal modes have a velocity antinode in the channels. The dissipation of these modes is greatly increased by viscous drag at the boundaries between the channels and the gas; thus, these modes are most sensitive to D_v . In contrast, even longitudinal modes have a temperature antinode in the channels. The dissipation of these modes will be greatly increased by irreversible heat conduction between the gas and the solid boundary during each acoustic cycle. Thus, the even modes are most sensitive to D_t of the gas. We measure the frequency response of the same resonator in the vicinity of both odd and even modes. From the measurements and our acoustic model, we can accurately determine the gas Prandtl number. Detailed knowledge of the geometry of the channels is not needed. The effective "hydraulic radius" of irregularly shaped channels can be determined by calibration with a suitable standard such as helium or argon. [Also, the thermal conductivity λ_c and the heat capacity per unit volume $(\rho C_p)_c$ of the channels' wall need not be known.] In a resonator calibrated with argon, the measured Prandtl number for helium agreed with ab initio calculations to ±0.3%. For propane, the measured Prandtl number agreed with literature values to within ±0.8%, which is the uncertainty in the thermal conductivity of propane.